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FEASIBILITY OF A PASSIVE THERMAL RADIATION FLUENCE TRANSDUCER.(U)

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FEASIBILITY OF A PASSIVE THERMAL RADIATION FLUENCE TRANSDUCER

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31 Jul[redacted]79

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A feasibility and exploratory development program is described for a simple passive thermal fluence transducer that provides high quality quantitative data on radiative heat sources. The feasibility is demonstrated by field test experiments for an inexpensive, passive recording transducer that augments and may replace expensive electronic calorimeters. These transducers are intended to provide post-test quick-look information on the incident heat from various nuclear thermal radiation simulators.

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PREFACE

This work was performed by the Los Alamos Technical Associates, Inc. (LATA) for the Defense Nuclear Agency (DNA) under contract DNA001-79-C-0092. Mr. Robert C. Webb of the DNA Shock Physics Directorate served as the Contracting Officer's Representative.

Mr. Peter S. Hughes of LATA was the chief investigator and program manager. Appreciation is expressed to Mr. S. Craig Newman and Mr. Bryan K. Stewart for their work in preparing test items and reducing test data.

CONVERSION FACTORS FOR U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

To Convert From	To	Multiply By
angstrom	meters (m)	1.000 000 × E -10
atmosphere (normal)	kilo pascal (kPa)	1.013 25 × E +2
bar	kilo pascal (kPa)	1.000 000 × E +2
barn	meter^2 (m^2)	1.000 000 × E -28
British thermal unit (thermochemical)	joule (J)	1.054 350 × E +3
cal (thermochemical)/cm^2*	mega joule/m^2 (MJ/m^2)	4.184 000 × E -2
calorie (thermochemical)*	joule (J)	4.184 000
calorie (thermochemical)/g*	joule per kilogram (J/kg)*	4.184 000 × E +3
curie	giga becquerel (GBq)††	3.700 000 × E +1
degree Celsius**	degree kelvin (K)	$t_K = t°_C + 273.15$
degree (angle)	radian (rad)	1.745 329 × E -2
degree Fahrenheit	degree kelvin (K)	$t_K = (t°_F + 459.67)/1.8$
electron volts*	joule (J)	1.602 19 × E -19
erg*	joule (J)	1.000 000 × E -7
erg/second	watt (W)	1.000 000 × E -7
foot	meter (m)	3.048 000 × E -1
foot-pound-force	joule (J)	1.355 818
gallon (U.S. liquid)	meter^3 (m^3)	3.785 412 × E -3
inch	meter (m)	2.540 000 × E -2
jerk	joule (J)	1.000 000 × E +9
joule/kilogram (J/kg) (radiation dose absorbed)*	gray (Gy)†	1.000 000
kilotons*	terajoules	4.183
kip (1000 lbf)	newton (N)	4.448 222 × E +3
kip/inch^2 (ksi)	kilo pascal (kPa)	6.894 757 × E +3
ktap	newton-second/m^2 (N-s/m^2)	1.000 000 × E +2
micron	meter (m)	1.000 000 × E -6
mil	meter (m)	2.540 000 × E -5
mile (international)	meter (m)	1.609 344 × E +3
ounce	kilogram (kg)	2.834 952 × E -2
pound-force (lbf avoirdupois)	newton (N)	4.448 222
pound-force inch	newton-meter (N·m)	1.129 848 × E -1
pound-force/inch	newton/meter (N/m)	1.751 268 × E +2
pound-force/foot^2	kilo pascal (kPa)	4.788 026 × E -2
pound-force/inch^2 (psi)	kilo pascal (kPa)	6.894 757
pound-mass (lbm avoirdupois)	kilogram (kg)	4.535 924 × E -1
pound-mass-foot^2 (moment of inertia)	kilogram-meter^2 (kg·m^2)	4.214 011 × E -2
pound-mass/foot^3	kilogram-meter^3 (kg/m^3)	1.601 846 × E +1
rad (radiation dose absorbed)*	gray (Gy)†	1.000 000 × E -2
roentgen*	coulomb/kilogram (C/kg)	2.579 760 × E -4
shake	second (s)	1.000 000 × E -8
slug	kilogram (kg)	1.459 390 × E +1
torr (mm Hg, 0° C)	kilo pascal (kPa)	1.333 22 × E -1

* These units should not be converted in DNA technical reports, however, a parenthetical conversion is permitted at the author's discretion.

** Temperature may be reported in degree Celsius as well as degree kelvin.

† The gray (Gy) is the accepted SI unit equivalent to the energy imparted by ionizing radiation to a mass of energy corresponding to one joule/kilogram.

†† The becquerel (Bq) is the SI unit of radioactivity. 1 Bq = 1 event/s.

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1.0 INTRODUCTION

1.1 BACKGROUND

This report documents the first phase in exploratory development of an inexpensive, passive thermal radiation fluence transducer. The basic research on such a transducer was completed by Mr. Peter S. Hughes of the Los Alamos Technical Associates, Inc. (LATA), and a patent application has been initiated. This basic research showed that the concept of a simple, field gage to record heat energy was fundamentally sound. Tests with various radiative sources confirmed the prediction that a simple passive transducer is practical and does in fact integrate the thermal flux.

1.2 STATEMENT OF PROBLEM

There is a pressing need for an inexpensive passive transducer because

(1) active instrumentation is expensive;

(2) reliable active instrumentation requires a great deal of care;

(3) active instrumentation is frequently limited by the number of available tape recorder channels;

(4) tests of large structures, e.g., aircraft structures, need many transducers to map the variations in the radiation incident on all parts of the structure; and

(5) active instrumentation usually does not provide quick, on-the-spot test results.

The recent Defense Nuclear Agency (DNA)-sponsored efforts by Mr. John Dishon of Science Applications, Inc., (SAI) have been successful in developing a fieldable heat source for simulating the thermal radiation from nuclear weapons. This facility (now located at Kirtland AFB (KAFB), New Mexico) is known as the

DNA Thermal Radiation Simulator (TRS). The chief advantage of the TRS is that it will permit the testing of large, full-scale structures and weapon systems, such as the testing of B-52 structures during July 1979.

Various prototype TRS testers were exercised at Sandia Albuquerque (February 1978); MISERS BLUFF event at Planet Ranch, Arizona (July 1978); Nevada Test Site (NTS) (October 1978 and December 1978); and KAFB (April 1979 and May 1979). These tests have unequivocally proven the need for a cheap passive thermal recording transducer such as the one invented by Mr. Hughes. LATA personnel were active participants in the test, and it became increasingly obvious that such a transducer was needed for the following reasons.

(1) The thermal data that are paramount for most nuclear effects tests are the thermal fluence (Q), not the thermal flux ($\dot{Q}$); only electronic flux calorimeters have been used in most of the previous tests.

(2) Historically, the data recovery rate using electronic calorimeters has been only fair; a variety of failures have occurred such as broken wires, preamplifier failure, amplifier failure, calorimeter burn-out, and tape recorder saturation.

(3) Occasionally the signal-to-noise (S/N) ratio has been unacceptably low. The December tests at NTS are a prime example where the S/N was quite low and valid data recovery was less than 50%. This was caused by a variety of sources in the electronic recording system.

(4) The active electronic instrumentation is so expensive that frequently only a small percentage of the desired locations are instrumented to record the incident thermal radiation--$2,000 to $3,000 per channel is not unusual; this was a particularly serious problem during the TRS calibration series at KAFB during April to May 1979.

(5) Unless there is a high speed computer available at the test site, active instrumentation does not provide the quick-look data needed to make timely decisions about the test results in the field. The invited observers, as well as the experimenters, need to know to what exposure levels the test specimens were subjected, immediately post-test.

These arguments are based upon observations while actually using thermal test facilities. They are the essential reasons why a passive transducer was developed, as documented in this report. The design goal attributes of a passive transducer and recording system are:

(1) simple to install;

(2) highly reliable;

(3) inexpensive;

(4) provides permanent recording;

(5) integrates the thermal flux to provide an on-the-spot reading of fluence;

(6) indicates the direction of the peak fluence to show if it was indeed normal to the test specimen surface; and

(7) provides a check on the post-test results of active recording and resolves questions regarding gain settings and other potential human errors.

2.0 PROTOTYPE TRANSDUCER DESIGN

2.1 RESULTS OF BASIC RESEARCH

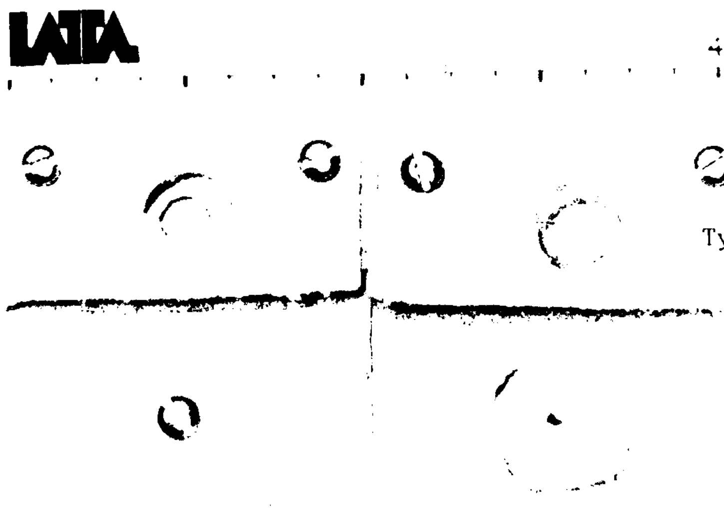
The basic research conducted by Mr. Hughes prior to this DNA-sponsored exploratory development resulted in the selection of stretched polystyrene sheet stock as the "active" heat sensing element in the passive transducers. This material absorbs infrared radiation, softens, and starts to shrink back to its originally manufactured size (details of polystyrene chemistry and wave length effects are discussed later in Section 3.0).

This research then involved a variety of geometrically-shaped sensing elements in an attempt to maximize the dynamic range (variation in fluence, Q) and minimize the difficulty in interpreting the results. This effort led to the transducer designs shown in Figures 2-1 and 2-2. As shown in Figure 2-1, the transducer has two different styles of sensing elements made from sheets of 10 mil (0.0254 cm), bidirectionally stretched polystyrene. These figures illustrate how the parts are assembled into a durable unit that is approximately 5 cm square.

The Type B element responds to the incident thermal load by growing outward towards the hole in the mask. This mask and the back frame are both made of asbestos board because of its low heat diffusivity and low reflectivity. The Type C elements are simply a stack of 1-in. squares of the polystyrene sheet. They respond by shrinking inward toward the center in pedal fashion. The concept is for the outer layers to shield the inner layers so that successive inner layers deform to a lesser extent. Then, following exposure to the thermal source, the deformation can be measured and provide a quantitative measurement of the incident heat.

2.2 RESULTS OF EXPLORATORY DEVELOPMENT

An operational test of the transducers occurred during the first calibration series on the DNA TRS facility, then installed at Frenchman's Flat at NTS. This calibration series of three events occurred during December 1979.



Type B Element

Type C Element

Assembled Transducer Before Exposure

Assembled Transducer After Exposure

Figure 2-1. Initial transducer designs: assembled configuration.

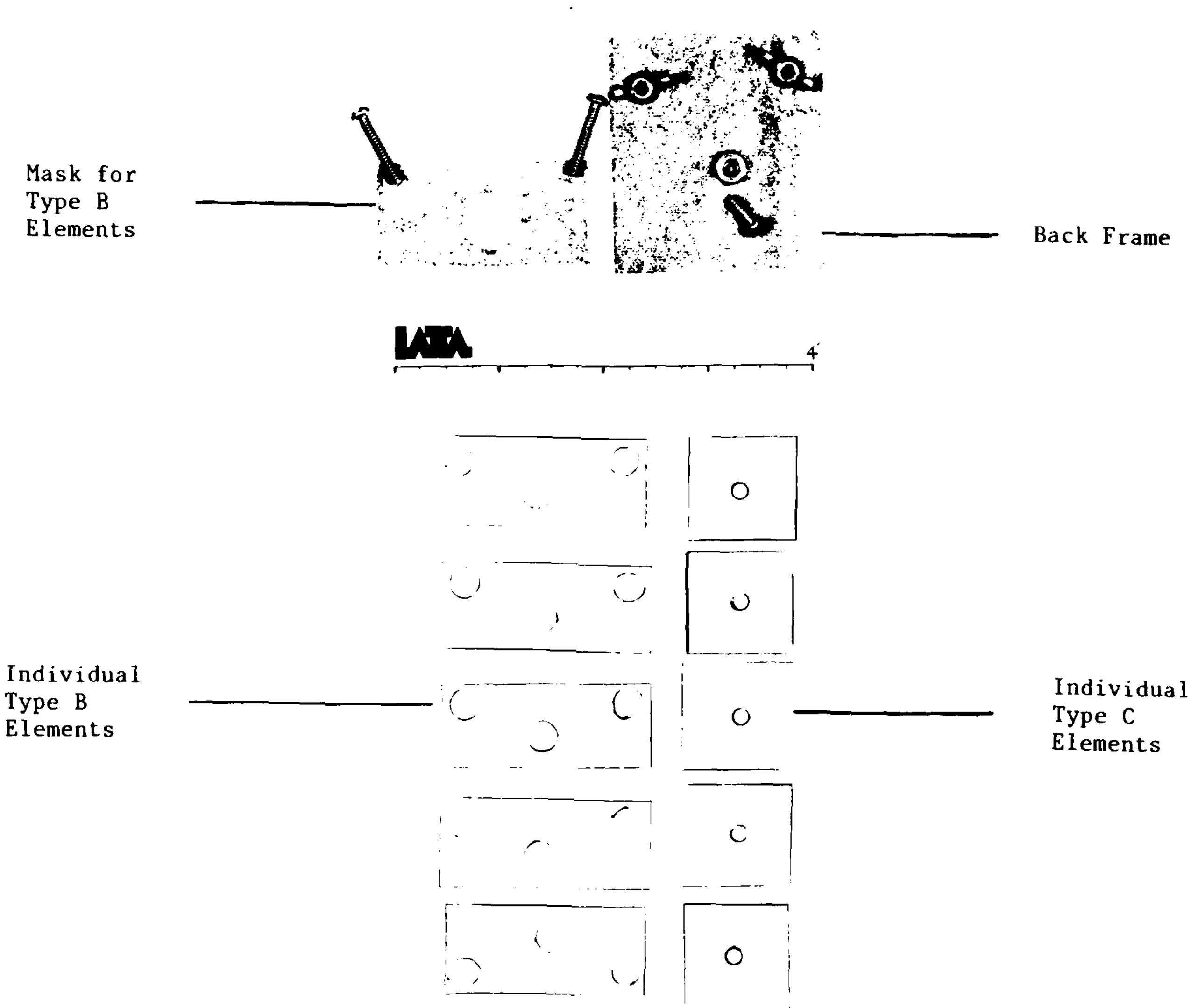


Figure 2-2. Initial transducer designs: exploded view.

A total of 50 of the experimental transducers were fielded on the three events, and in every case, they were co-located with an electronic calorimeter. Some of these calorimeters were supplied by Rockwell International, and others were fielded by the SAI personnel who had the active data recording responsibility.

2.2.1 Test Event 1

The first TRS calibration event consisted of a 2 x 2 array of thermal bags. Eighteen passive transducers were fielded on this event, which occurred on December 7.

All of the passive transducers functioned as designed; however, the active data recording performed poorly and there were such problems as (1) low signal-to-noise ratio, (2) 60 Hz noise interference, and (3) broken or burned-through wiring from the calorimeters. It is estimated that only six of the 16 active channels yielded valid data.

In general, the thermal output from the TRS was much more intense than predicted. This was unfortunate because several of the passive, as well as active, transducers were destroyed by thermal fluences in excess of 100 cal/cm^2. As far as the passive transducer calibration was concerned, the electronic calorimeters provided only two valid data points.

2.2.2 Test Event 2

The second TRS calibration event used a 2 x 4 array of thermal bags. Twenty passive transducers were fielded on this shot, which occurred on December 8. Again the active instrumentation was plagued with a myriad of problems. It is estimated that only seven channels out of a total of 19 gave reliable calorimeter data.

The passive transducers functioned; however, contrary to preshot predictions from SAI, the fireball was so large that it engulfed many of the transducers and exceeded their usable upper limit, which appeared to be about 30 to 40 cal/cm^2. The active calorimeters provided only three valid data points.

2.2.3 Test Event 3

The third TRS event was fired on December 8 and again consisted of a 2 x 4 thermal bag array. It is estimated that from a total of 19 active calorimeter channels, 10 gave reliable data. Twelve passive transducers were fielded and recovered; however, the active electronic calorimeters only provided four valid calibration data points for these passive transducers.

2.2.4 Summary of NTS Calibration Series

Overall, this test series was disappointing; consequently, it was terminated before all the scheduled events took place. It was felt by all the test party that there were too many problems to continue. These were problems with (1) the electronic recording system, (2) the wind causing fireball drift, (3) the lack of shot-to-shot consistency with bag ignition, and (4) the difficult logistics of operating at the Frenchman's Flats Site.

The passive gages functioned reliably and consistently and a great deal of valid calibration data would have been obtained if (1) the preshot fluence level predictions had been more accurate (predictions were low; consequently, the transducers were placed too close to the source); and (2) the active instrumentation had performed as expected and yielded reliable data to calibrate the passive transducers.

In general, the passive transducers performed as designed with both types of sensing elements providing a permanent record of the incident fluence. Figure 2-3 shows some examples of these two types of elements exposed to different fluences.

The sensing element deformations were consistent for exposures to the same fluence. It became obvious during the test series that such passive instrumentation was a valuable tool (1) to monitor shot-to-shot consistency, (2) to map out iso-fluence contours on the test bed, (3) to provide instant feedback to the experimenters about the test performance, and (4) to provide a confirmation that the active channels in fact actually had the gain settings that were designed.

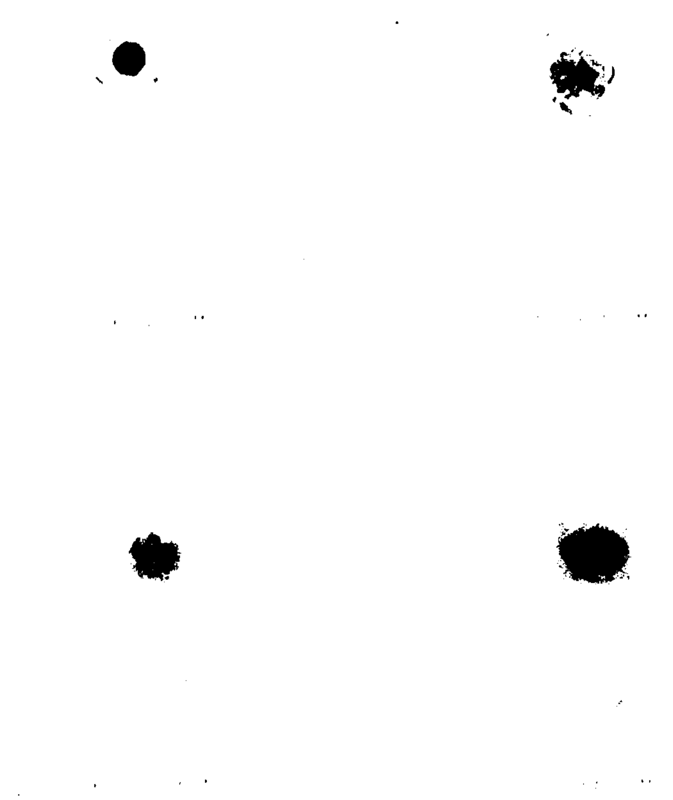


Figure 2-3. Examples of sensing elements exposed to different fluence levels.

After carefully reviewing the recorded active calorimeter data from the three events, it was decided not to attempt to plot a calibration curve for the passive transducers. There was not a statistically significant quantity of reliable data points to compare with the measured deflections of the passive sensing elements. Paramount in this decision was the knowledge that subsequent field tests of the TRS system were to take place after the facility was relocated at KAFB. These tests would provide an opportunity to obtain a great quantity of high-quality active data to characterize the TRS thermal output and to calibrate the passive gages.

2.2.5 Preliminary Results from TRS Testing at KAFB

Although not in the original scope of work, the TRS calibration series at KAFB represented an opportunity to obtain the passive gage calibration data that failed to materialize during the NTS tests. The tests at KAFB were intended to include detailed diagnostics for a thorough calibration of the TRS that was relocated from the NTS Site to the Coyote Canyon Site at KAFB. A four-shot test series occurred during the period April 26, 1979 through May 4, 1979.

Approxim tely 50 passive transducers were fielded on each event in a 360 degree pattern around the TRS linear array of 16 thermal bags. Once again there were problems with the electronic calorimeters; however, after the first shot, data recovery was excellent. Nevertheless, it can be categorically stated that the passive transducers were instrumental in the success of this test series. They permitted a detailed mapping of the iso-fluence contours around the test bed, and the instantaneous, post-test data display from the 50 transducers allowed the LATA test director to quickly make decisions affecting each subsequent test.

The transducer model that was used during the TRS testing at KAFB is shown in Figure 2-4. More than 400 data points were recorded by the passive transducers. The reduction of this data is awaiting further DNA funding (Phase 2 transducer development). However, for completeness of this report, a preliminary calibration curve was derived from this data for the Type C sensing elements (1-in. squares). This calibration curve (Figure 2-5) is used by post-test

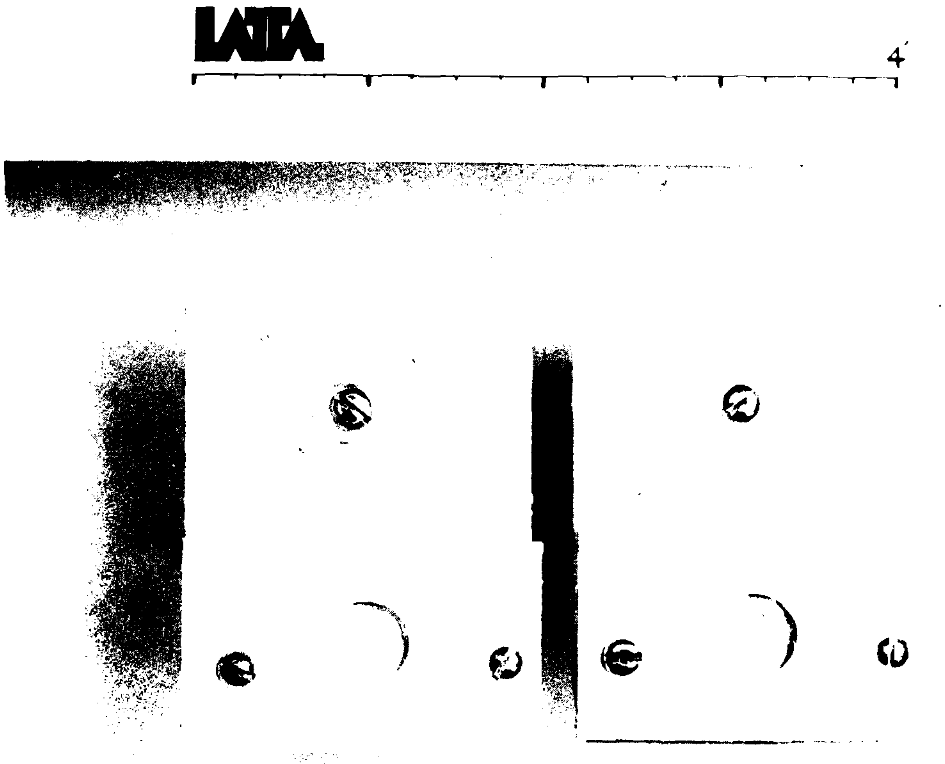


Figure 2-4. Production model transducer used during TRS calibration at Kirtland Air Force Base.

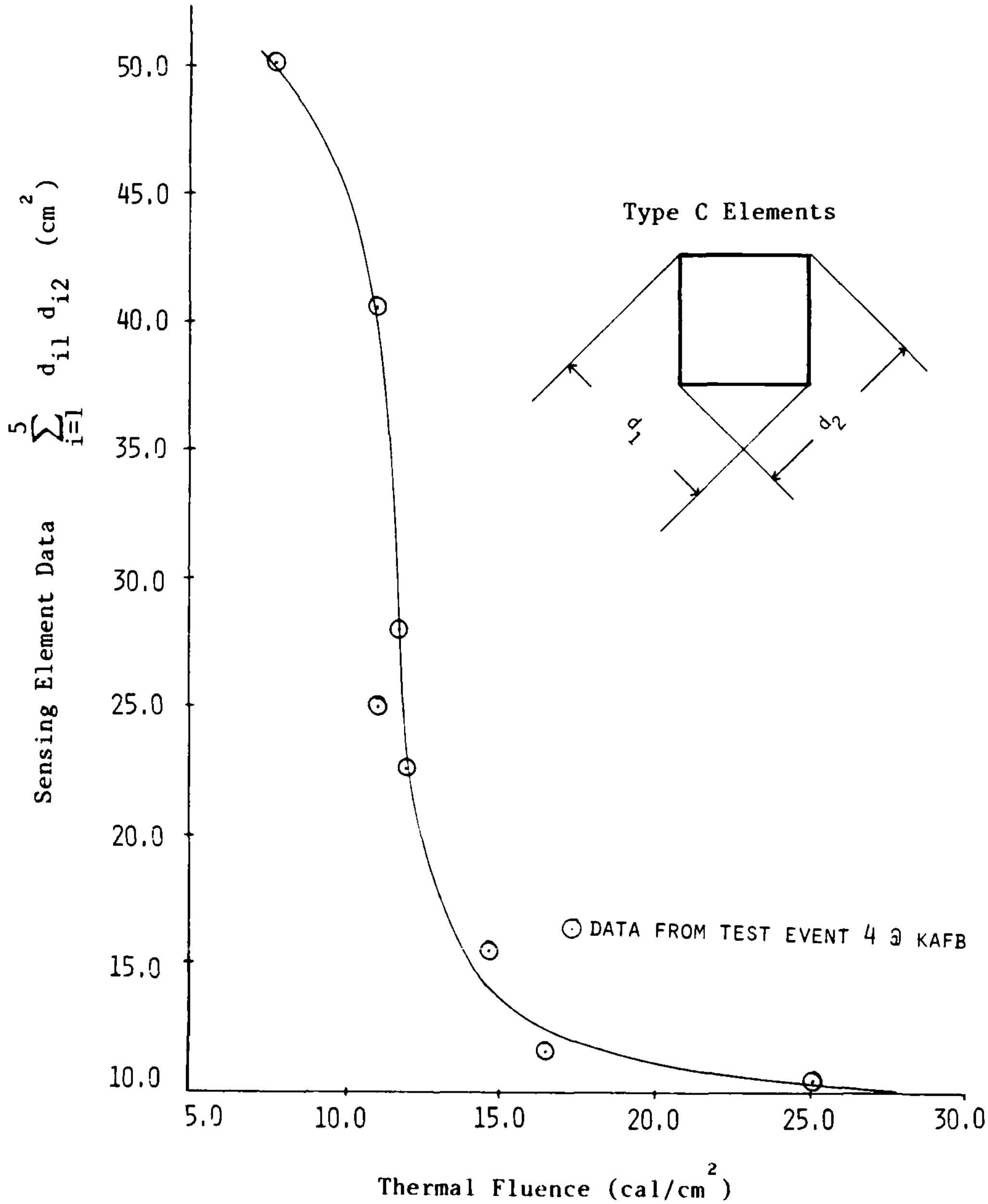


Figure 2-5. Preliminary calibration curve for passive transducer Type C sensing elements.

measurement of the two diagonal dimensions of each layer of polystyrene. Then the two measurements for each respective layer are multiplied and summed up over the total number of layers. Mathematically this is expressed as

$$\text{Calibration parameter} = \sum_{i=1}^{5} d_{i1}\, d_{i2}$$

where d_{i1} and d_{i2} are the first and second diagonals of the polystyrene layers (i).

The proposed follow-on Phase 2 transducer development will explore different methods of post-test sensor element measurement and perhaps a more usable calibration curve. Nevertheless, the calibration curve in Figure 2-5 shows that the passive transducers do provide quantitative information. It appears that the sensor element deformations can be used to determine the incident thermal fluence to an accuracy of about ±2 cal/cm^2. Hopefully a method can be devised whereby the accuracy is a linear function of the fluence, such as ±10% of Q.

3.0 PROPERTIES OF POLYSTYRENE SENSING ELEMENTS

Polystyrene is produced by the polymerization of the monomer styrene:

$$\text{monomer (styrene)} \qquad (C_6H_5) - CH = CH_2$$

In general, the accepted structure of polystyrene is shown below:

$$\left(- CH_2 - \underset{\displaystyle C_6H_5}{\underset{|}{CH}} - \right)_n$$

where n is roughly 2,000.

In actuality, the carbon chains vary in length and the end valences are saturated with catalyst, solvent, or impurity molecules. It should be noted that polystyrene is an amorphous material and therefore it does not have a unique unit structure; instead it consists of many different structural states. Orientation of polymer chains, and nonequilibrium configurations are the two most important variables affecting the different states. Both depend on the manner in which the product was produced, which in turn affects the physical and thermal properties of polystyrene.

Thermally, polystyrene is very stable up to the distortion temperature (82 to 88°C). Under certain test conditions, the distortion temperature can be measured accurately and is found to be quite sharp and well defined. During production, the distortion temperature of the polystyrene product can be lowered by addition of plasticizers, residual solvents, or unpolymerized monomers.

Another variable parameter dependent upon production procedure is the amount of distortion. At or above the distortion temperature, the amount of distortion is determined by the quantity of "frozen in" strain incurred during molding. High temperature molding produces minimum strain, whereas low temperature molding produces high strain.

The optical properties of sheet polystyrene are described by Figures 3-1 through 3-4.[1] Figure 3-1 illustrates that the transmission of electromagnetic energy across the visible spectrum is about 90%. This high transmission is largely due to the absence of chromaphoric groups in the polystyrene molecule. This high transmission continues a short way into the ultraviolet wavelengths. Figure 3-2 shows that there is a fairly sharp transmission cut off at wave lengths shorter than about 0.25 to 0.3 μ. This effect is due to the absorption by the styrene monomer. A transducer with polystyrene elements could also be used to measure the incident energy in the ultraviolet spectrum from a radiative source. The initial transducer development has necessarily concentrated upon measurements in the infrared spectrum; however, follow-on phases of this work will explore the feasibility of building a practical transducer to record ultraviolet radiation.

Figure 3-3 illustrates details of the transmission qualities of the polystyrene transducer elements over the near infrared spectrum. This data were taken on 2 mil sheet stock and shows an average transmission of roughly 50%. This data, from Reference 1, is somewhat contradictory with the data presented in Figure 3-4 (same reference), which implies that polystyrene is totally opaque to wave lengths between 5 and 20 μ. It is suggested that the Figure 3-4 data be used as a qualitative measure of general trends and the Figure 3-3 data be used quantitatively for detail transmission in the near infrared region.

Some additional properties of polystyrene that make it a good choice for a fieldable passive transducer element are as follows:

(1) It has low moisture absorptivity, e.g., 0.03 to 0.04% in 24 hours;

(2) It is good for continuous use in field applications because it is stable to at least 150°F;

(3) It has only a very slight degradation during prolonged exposure to sunlight.

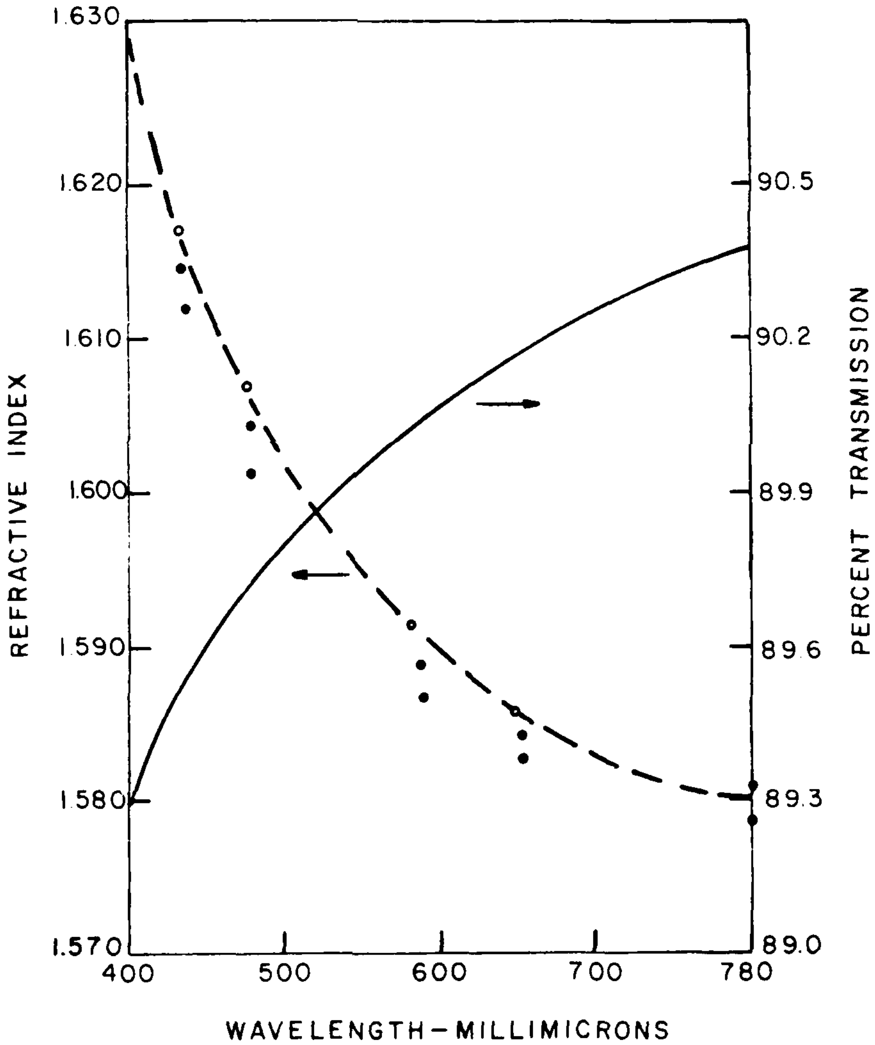


Figure 3-1. Transmission characteristics of sheet polystyrene: visible spectrum.

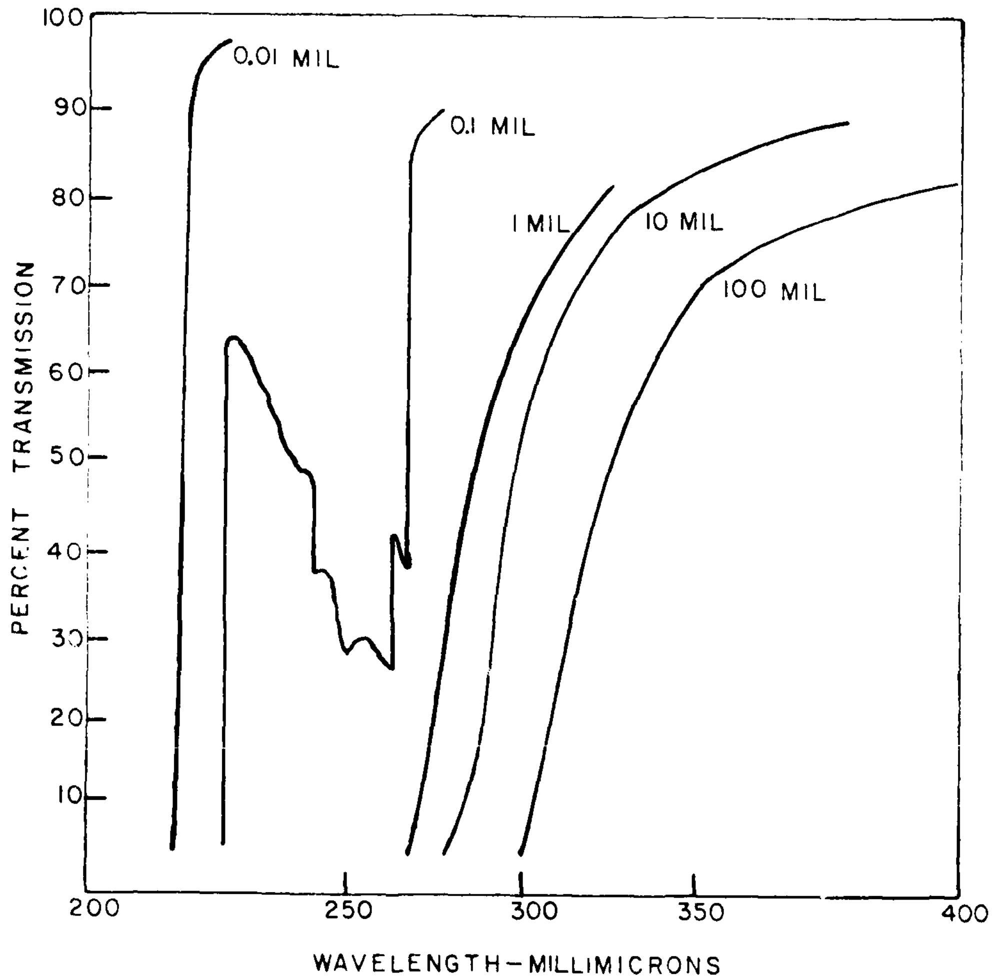


Figure 3-2. Ultraviolet transmission curves for polystyrene.

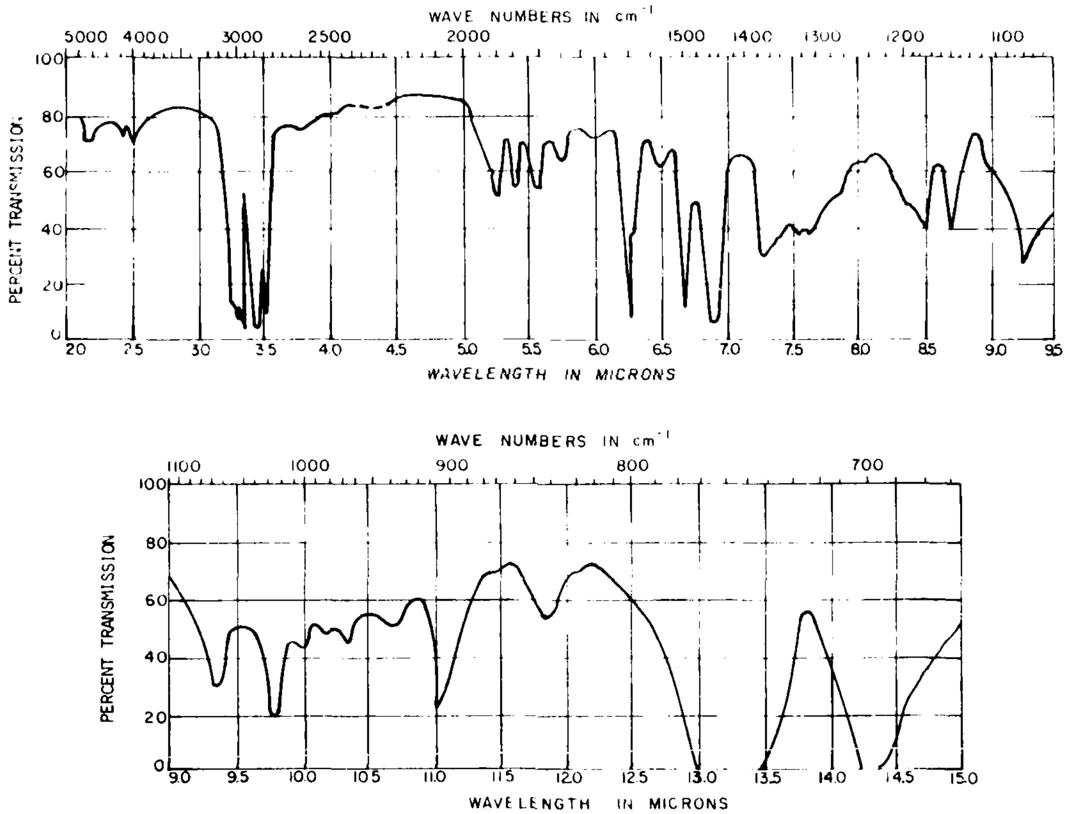


Figure 3-3. Infrared transmission of polystyrene.

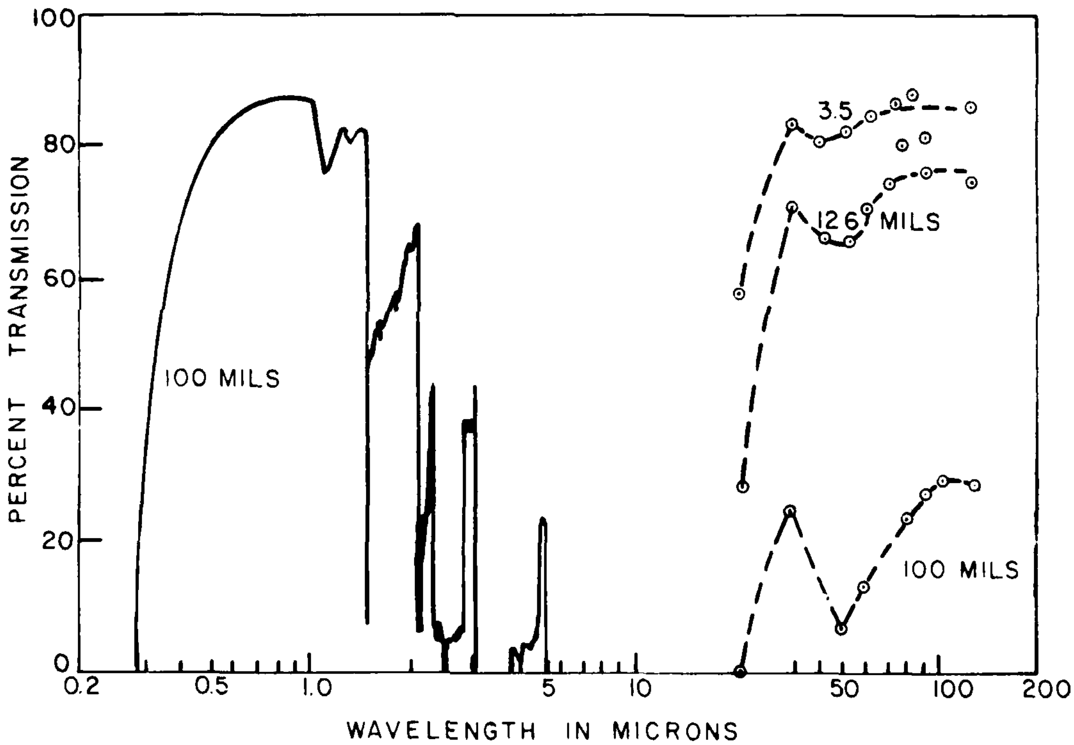


Figure 3-4. Transmission of polystyrene: illustration of visible window and ir opacity.

4.0 CONCLUSIONS

The overall conclusion is that it is feasible to build a simple passive thermal fluence transducer that provides high-quality quantitative data on radiative heat sources. Some specific conclusions are as follows:

(1) Sheet polystyrene is an adequate material for manufacturing the thermally sensitive elements; i.e., it absorbs a significant portion of the infrared spectrum.

(2) The sheet polystyrene may also make a good sensor element for measurement of ultraviolet radiation.

(3) Both element configurations (Type B and Type C) are good indicators of the direction of the peak thermal fluence; this is a distinct advantage over electronic calorimeters.

(4) At this early stage in the development, it is estimated that the transducer has a usable range of from 5 cal/cm^2 to about 40 cal/cm^2; this range may be extended as development continues.

(5) The accuracy appears to be about ±2 cal/cm^2 with the present measurement techniques.

(6) The current transducer design can readily be read in situ, as mounted in the field, thus facilitating immediate post-test inspection.

(7) The transducer design is both simple and inexpensive; it is estimated that the unit cost, in prototype quantities, is less than $30.

5.0 RECOMMENDATIONS

The general recommendation is to continue development of the passive transducers. They show excellent promise and potentially could be at least as accurate as active calorimeters and yet less expensive and inherently more reliable. Some specific recommendations are as follows:

(1) Perform a series of passive transducer calibration tests in the Tri-Services Thermal Radiation Facility at Wright-Patterson AFB, Ohio. This carefully controlled environment is needed to determine the minimum and maximum extremes of the usable thermal fluence range.

(2) Reduce the data from the recently completed TRS testing at KAFB. The more than 400 data points will allow more statistically accurate calibration curves to be constructed for both sensing element types.

(3) Pursue the transducer development into a second phase of design modifications concentrating on

(a) sensitivity,

(b) ease in reading,

(c) minimizing unit cost,

(d) increasing reusability, and

(e) increasing ease of application.

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ATTN: Strategic & Space Systems (OS)

DEPARTMENT OF THE ARMY

Atmospheric Sciences Laboratory
U.S. Army Electronics R&D Command
ATTN: DELAS-EO

BMD Advanced Technology Center
Department of the Army
ATTN: ATC-T

BMD Program Office
Department of the Army
ATTN: DACS-BMZ
ATTN: DACS-BMT

BMD Systems Command
Department of the Army
ATTN: BDMSC-H
ATTN: BMDSC-NW

Chief of Engineers
Department of the Army
ATTN: DAEN-ZCM

Deputy Chief of Staff for Ops. & Plans
Department of the Army
ATTN: DAMO-NCZ

Deputy Chief of Staff for Rsch. Dev. & Acq.
Department of the Army
ATTN: DAMA-CSM-N

Electronics Tech. & Devices Lab.
U.S. Army Electronics R&D Command
ATTN: DELET-ER

Harry Diamond Laboratories
Department of the Army
ATTN: DELHD-I-TL
ATTN: DELHD-N-P
ATTN: DELHD-N-TS

U.S. Army Armament Research & Development Command
ATTN: DRDAR-LCS-W
ATTN: DRDAR-LCN
ATTN: DRDAR-LCE
ATTN: DRDAR-LCW
ATTN: DRDAR-LC

U.S. Army Ballistic Research Labs
ATTN: DRDAR-BLT
ATTN: DRDAR-TSB-S
ATTN: DRDAR-BLE
ATTN: DRDAR-BLV

U.S. Army Communications Command
ATTN: CC-OPS-PD

U.S. Army Engr. Waterways Exper. Station
ATTN: WESSD
ATTN: WESGR
ATTN: WESSA
ATTN: WESSE
ATTN: WESGH
ATTN: WESSS

DEPARTMENT OF THE ARMY (Continued)

U.S. Army Health Services Command
ATTN: Plans & Operations Division

U.S. Army Material & Mechanics Rsch Ctr.
ATTN: DRXMR-HH

U.S. Army Materiel Dev. & Readiness Cmd.
ATTN: DRXAM-TL
ATTN: DRCDE-D

U.S. Army Missile R&D Command
ATTN: DRCPM-PE
ATTN: DRDMI-TKP
ATTN: DRDMI-TRR
ATTN: RSIC

U.S. Army Nuclear & Chemical Agency
ATTN: Library for ATCA-NAW
ATTN: MONA-WE
ATTN: Library for MONA-SAL

U.S. Army Satellite Comm. Agency
ATTN: Technical Library

U.S. Army Training and Doctrine Cmd.
ATTN: ATORI-OP
ATTN: ATCD-T

White Sands Missile Range
Department of the Army
ATTN: STEWS-FE-R

DEPARTMENT OF THE NAVY

Supervisor of Shipbuilding
Conversion and Repair
Department of the Navy
ATTN: S. Gianodo

David Taylor Naval Ship R&D Ctr.
ATTN: Code 17

David Taylor Naval Ship R&D Ctr.
Underwater Explosions Rsch. Division
ATTN: Code 770

Naval Coastal Systems Laboratory
ATTN: D. Sheppard

Naval Facilities Engineering Command
ATTN: Code 09M22C

Naval Material Command
ATTN: MAT-0323

Naval Ocean Systems Center
ATTN: W. Shaw

Naval Research Laboratory
ATTN: Code 7780
ATTN: Code 6770
ATTN: Code 2627

Naval Sea Systems Command
ATTN: SEA-0352

Naval Weapons Center
ATTN: Code 31707

DEPARTMENT OF THE NAVY (Continued)

Naval Surface Weapons Center
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ATTN: Code E21
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Office of Naval Research
ATTN: Code 715

Office of the Chief of Naval Operations
ATTN: OP 981
ATTN: OP 604E14
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Strategic Systems Project Office
Department of the Navy
ATTN: NSP-272

DEPARTMENT OF THE AIR FORCE

Aeronautical Systems Division
Air Force Systems Command
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Air Force Flight Dynamics Laboratory
ATTN: FXG

Air Force Geophysics Laboratory
ATTN: LY

Air Force Institute of Technology
ATTN: Library

Air Force Materials Laboratory
ATTN: LPH
ATTN: MAS
ATTN: MBE
ATTN: MBC

Air Force Rocket Propulsion Laboratory
ATTN: LKCP

Air Force Systems Command
ATTN: XRTO
ATTN: SOSS

Air Force Weapons Laboratory
Air Force Systems Command
ATTN: DYS
ATTN: SAB
ATTN: DYT
ATTN: DYV
ATTN: SUL
ATTN: NTO

Arnold Engineering Development Center
Air Force Systems Command
ATTN: Library Documents

Ballistic Missile Office
Air Force Systems Command
ATTN: MNRTE
ATTN: MNNR
ATTN: MNNH

DEPARTMENT OF THE AIR FORCE (Continued)

Deputy Chief of Staff
Operations Plans and Readiness
Department of the Air Force
ATTN: AFXOOSS

Deputy Chief of Staff
Research, Development, & Acq.
Department of the Air Force
ATTN: AFRD
ATTN: AFRDQSM
ATTN: AFRDQ

Foreign Technology Division
Air Force Systems Command
ATTN: PDBG
ATTN: TDFBD
ATTN: TOPTN

Headquarters Space Division
Air Force Systems Command
ATTN: RST
ATTN: RSS

Strategic Air Command
Department of the Air Force
ATTN: XPFS
ATTN: XPQM
ATTN: DOXT
ATTN: XOBM

DEPARTMENT OF ENERGY

Department of Energy
ATTN: OMA/RD&T

DEPARTMENT OF ENERGY CONTRACTORS

Lawrence Livermore National Laboratory
ATTN: L-125, J. Keller
ATTN: L-262, J. Knox
ATTN: L-24, G. Staihle
ATTN: L-92, C. Taylor

Los Alamos National Scientific Laboratory
ATTN: MS 670, J. Hopkins

OTHER GOVERNMENT AGENCY

Federal Emergency Management Agency
ATTN: Asst. Dir. for Rsch., J. Buchanon

DEPARTMENT OF DEFENSE CONTRACTORS

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ATTN: J. McClelland

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ATTN: J. Selig

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Boeing Co.
ATTN: R. Holmes
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California Research & Technology, Inc.
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Eric H. Wang
Civil Engineering Rsch. Fac.
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General Electric Company—TEMPO
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General Electric Company—TEMPO
ATTN: DASIAC

General Electric Company—TEMPO
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ATTN: T. Stathacopoulos

Institute for Defense Analyses
ATTN: Library

Kaman AviDyne
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Lockheed Missiles & Space Co., Inc.
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Lockheed Missiles & Space Co., Inc.
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Northrop Corp.
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ATTN: D. Hove
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Science Applications, Inc.
ATTN: W. Layson

Science Applications, Inc.
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DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

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SRI International
ATTN: A. Burns
ATTN: H. Lindberg
ATTN: G. Abrahamson

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ATTN: R. Duff

Teledyne Brown Engineering
ATTN: R. Patrick

Terra Tek, Inc.
ATTN: S. Green

TRW Defense & Space Sys. Group
ATTN: N. Lipner

TRW Defense & Space Sys. Group
ATTN: R. Mortensen
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